Rhodora

JOURNAL OF

THE NEW ENGLAND BOTANICAL CLUB

Vol. 11. December, 1909. No. 132.

THE SUBMARINE CHAMAECYPARIS BOG AT WOODS HOLE, MASSACHUSETTS.[1]

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(Plate 82.)

The bog which is described in this paper is of unusual interest from two stand-points,— to the botanist because it illustrates the genesis of a typical salt-marsh from a fresh water bog, to the geologist because it affords evidence of post-glacial subsidence in the Cape Cod district. It is probable that the origin of salt-marshes through invasion of fresh water bogs by the sea has not been infrequent on the New England coast, but with the exception of a recent paper by Penhallow, very little has been written on the subject. The question of post-glacial subsidence, on the other hand, has been much discussed. It hardly comes within the scope of this paper more than to state that geologists have shown that such a subsidence has taken place from Nova Scotia to New Jersey, and that it is still in progress. Along certain parts of the coast, however, evidence of subsidence has either never been carefully studied, or has been considered inadquate. For example, Penhallow[2] quotes Mr. Fuller of the United States Geological Survey as follows: — "Of the instances [of submerged stumps and peat masses] mentioned by Shaler and others in Massachusetts, those at Nantucket and Truro are perhaps the most prominent. The submerged stumps at Truro have, in part at least, reached their present position by undermining. I have not examined the Nantucket locality. There appears, however, on the whole, to be very little evidence of a post-glacial subsidence in this region, although Dr. T. A. Jaggar a few

[1] Published by permission of the Director of the U. S. Geological Survey.

[2] Trans. Roy. Soc. Can. 3d. Ser. vol. i, section iv (1907), p. 22.

years ago concluded from observations on wharves at Boston, that there had been a sinking of two feet during the past century." In view of this statement, the presentation of new evidence concerning subsidence in the Cape Cod district seems to be justified.

Before discussing either the formation of salt-marshes or the question of subsidence, it will be necessary to describe in brief the topography of the region about Woods Hole, and, rather more in detail, certain features in the historical development of the Chamaecyparis bogs which are found there.

Woods Hole lies at the southern extremity of the basal lobe of Cape Cod, on the Falmouth continuation of the Plymouth moraine. The glacial drift is for the most part very coarse, and readily permeable to water. The water table is reached at slight depths. Northward from the village the surface is characterized by a number of kettle holes,— steep-walled depressions in the till supposed to have been formed by the melting of isolated masses of buried or imbedded ice after the recession of the ice sheet. These are occupied either by ponds or by Chamaecyparis bogs, and are, of course, undrained. Their vegetation was described several years ago by C. H. Shaw.[1] Although his paper gives a good idea of the present flora of the bogs, it is inaccurate in so far as it relates to their development.

The typical ice-block hole has steep sides, and, comparatively speaking, a flat bottom. The vegetation which occupies it belongs to one of four types, which are determined by the relation of the water table to the surface of the ground. 1) The water table is far enough below the ground surface so that the mesophytic vegetation of hillsides and valleys becomes established. This condition is uncommon about Woods Hole because the water table is very close to the surface. 2) The water table practically coincides with the floor of the depression, so that conditions favor a hydrophytic vegetation. In holes of this type Chamaecyparis bogs have developed. 3) The water table intersects the ground level on the gently sloping floor of the hole. In this case there is a shallow pond at the center, with an annular area around it, where, as in a hole of the last type, the water table is near the surface of the ground and conditions are favorable for *Chamaecyparis*. 4) The water table intersects the steep sides of the depression. Here there is no habitat favorable for *Chamaecyparis*.

[1] The Development of Vegetation in the Morainal Depressions of the Vicinity of Woods Hole. Bot. Gaz. xxxiii, (1902) p. 437.

Moreover, since the usual kettle-hole pond has no outlet, great seasonal fluctuation in water level prevents mat-forming plants from getting a foothold. The pond in a depression of this type remains open, and usually has a gravelly beach.

Mr. Shaw's studies led him to believe that the Woods Hole Chamaecyparis bogs had been formed by the growth of *Chamaecyparis* on floating mats after they had already become firm enough to be occupied by a thicket of various shrubs. In accord with this idea, he termed the shrubs which are found in the cedar bogs, *Leucothoë, Kalmia angustifolia*, etc., relicts from a former thicket vegetation. In his paper three individual bogs are described, designated as "x," "y" and "z." Bog "x" differs from bogs "y" and "z" chiefly in having a pool at the center, which Mr. Shaw considers to have been a remnant of open water at the center of the pond when *Chamaecyparis* took possession of the mat. Soundings show the incorrectness of this conclusion. As a matter of fact, bogs "y" and "z" seem to have developed in depressions of the second type defined in the preceding paragraph, and bog "x" probably in a depression of the third type. In all three bogs, the peat contains Chamaecyparis stumps and roots *in situ* from top to bottom. There is no trace of a mat. Throughout their history, the increase in thickness of peat in these bogs has been accompanied by a corresponding rise of the water table, the mechanism of which is easily explained.

Let us assume, for the sake of argument, the existence of a flat water table beneath an uneven ground surface. Supposing that the capacity for loss of water at the ground surface through evaporation and plant transpiration were uniform over the whole area, then the amount of water lifted by capillarity from the water table to the ground surface and there lost by evaporation would vary inversely as the distance between the two surfaces. The limiting condition which would be approached through the operation of this one factor would be parallelism of water table and ground surface. Rain, falling upon the surface, would be, over a small area, evenly distributed. By far the larger part would sink into a porous soil at once. Since its movement would then be controlled only by gravitation, it would be added to the water table in a layer of uniform thickness, and would not tend to modify the parallelism of the water table and the ground surface. Two factors would tend to have a flattening effect on the water table,— the filling of its depressions by run-off water and the operation of hydrostatic pressure. The latter would bring about final equilibrium. High levels of the water table would sink, and low levels rise, until the pressure gradient from high to low levels balanced the resistance offered by the soil to the passage of water through it from points at the high level to points at the low level. This would be the condition of equilibrium.

Applying these considerations to kettle holes, we see:— 1) that the water level in such a hole marks the lowest level in the water table of its drainage area, 2) that by replacing the kettle hole by a high hill, the same area might be made to coincide with the area of greatest elevation of the water table, and 3) that between these two conditions of the water table, any intermediate condition might be established by gradually filling the depression with a porous medium, such as soil or peat. The growth of a peat deposit in a kettle hole would continue until the water table lagged too far behind the bog level to provide sufficient moisture for preservation of peat from atmospheric oxidation.

We may now turn to the bog which it is the special object of this paper to describe.

As one walks along the shore from Woods Hole to Quamquisset, a salt-marsh is encountered which forms a prolongation of a slight lobe of the harbor. Its greatest width is about four hundred and fifty feet; its length perhaps twelve hundred feet. Seven hundred feet inland there is a constriction where the width is only about forty feet. So far as the vegetation is concerned, the seaward portion is a typical salt-meadow. Otherwise, however, it presents two anomalous features, in that it is neither penetrated by a tidal creek nor protected from the sea by a barrier beach. The explanation of this unusual topography is disclosed at low tide, in a line of stumps and prone logs along the water's edge,— the stumps in the position in which the trees grew. These show that our salt marsh is a peat bog which the sea has invaded, not a tidal flat built up through the usual agencies of salt-marsh formation. The stumps lie in the face of an escarpment only a foot or so high, formed by undercutting of the peat in which they are imbedded. At the surface the peat is protected from erosion by three or four inches of tough Spartina turf. At high tide this turf is submerged; at low tide a few feet of beach slopes gradually from the escarpment to the water. On the beach the peat is covered by a few inches of pebbles and bowlders, thrown up by the waves. Plate 82 is from a photograph of the shore, taken at low tide.

Microscopical examination of wood from the stumps has shown that the trees were *Chamaecyparis thyoides*. Some of them, between three and four feet in diameter, were larger than any trees of this species now found in the vicinity of Woods Hole. The wood is still solid, and wonderfully preserved. When cut after the salt water has dried out, it is as fragrant as though fresh. Besides wood, the peat contains seeds of *Chamaecyparis* and countless little rod-like particles of resin which appear to have been derived from the glands on its scale-like leaves. Other identifiable remains are *Sphagnum*, seeds of an alder, and achenes of sedges. Throughout the entire marsh the character of the peat is the same. Wood is found at all depths. This fact, taken in conjunction with the general topography of the depression, leaves no doubt but that our marsh is a kettle hole Chamaecyparis bog drowned by the sea. This conclusion is borne out by a study of the zonation of vegetation in the marsh, for in the extreme landward part *Chamaecyparis* is still growing, and peat similar to that which underlies the salt-marsh is still forming. Soundings in this part of the bog show that its history as a Chamaecyparis bog has been unbroken. It has never been submerged below sea level, for there is no stratification of the peat which would indicate this. In recent times, however, there have been no trees in this part of the bog as large as those found at depths of three or four feet, which correspond in age to those exposed in the peat at the edge of the salt-marsh.

No doubt most botanists are familiar with Shaler's papers [1] in which the zonation of salt-marshes and the plant succession concomitant with their upward growth are described. *Zostera* and various sea weeds, growing densely on shallow bottoms, retard the velocity of tidal water so that it deposits among them part of the sediment which it carries in suspension. When by this means a tidal flat has been built up sufficiently, *Spartina glabra* establishes itself and collects sediment even more efficiently than the eel-grass. Finally, when the marsh has been built practically to high tide level, *Spartina glabra* is for the most part replaced by *Spartina patens* and *Juncus Gerardi*. A growing marsh shows these three zones, which are represented in a vertical section of a mature marsh by three corresponding strata.

[1] Sea-Coast Swamps of the Eastern United States. 6th Ann. Report U. S. Geol. Surv. (1884–85) p. 359.

Beaches and Tidal Marshes of the Atlantic Coast. National Geographic Monographs, i no. 4 (1895) p. 137.

The history of the Quamquisset marsh has been almost the reverse of this. The fresh water flora of a Chamaecyparis bog, which was cut into at one end by wave erosion, was killed back for a considerable distance from the sea. In consequence, the deposition of peat in this part of the bog was practically stopped, although it was not interrupted further inland. Ultimately a sloping surface was established. When, by subsidence of the whole area, the lowest part of this slope reached the high tide level, *Spartina patens* and *Juncus Gerardi* occupied it. After further subsidence, *Spartina glabra* replaced these two species, which moved farther up the slope. In this case it will be noticed that the order of the two zones from the sea landward is the same as in a typical salt-marsh, but that the vertical arrangement of the strata is just the reverse.

Under ordinary circumstances, the growth in thickness of *Spartina patens* turf is very rapid, and easily keeps pace with the lowering of a marsh surface by subsidence, but at Quamquisset Harbor very little silt is brought in by the inflowing tides and still less is derived from the surrounding slopes, so that the salt-marsh deposits consist of a densely matted mass of root stocks at most a few inches thick. In more typical salt-marshes the Spartina turf usually contains far more silt than organic matter, and is therefore less compact.

Between the two zones of markedly halophilous plants and the fresh bog vegetation above high tide level occur two zones the flora of which consists of facultative halophytes. Among them are halophytes which grow as well in a non-saline as in a saline situation (e. g. *Triglochin maritima, Ptilimnium capillaceum*, etc.) and, conversely, plants which are typical of our upland fields and woodland (e. g. *Aspidium Thelypteris, Rhus Toxicodendron*). Athough these plants are subjected to great extremes of salinity (their varying ability to withstand which probably accounts for their zonation), the analytical data presented below show that in at least the upper of the two zones, the salinity at the height of the growing season is very slight indeed. In this connection the conclusions of Kearny [1] and of Olsson-Seffer [2] in regard to the salinity of soil water on sea beaches have an important bearing. Briefly summarized, they are as follows: — 1) that the salinity of the soil water of the middle and upper beaches is in reality very slight, but, as in the transition zones of the salt marsh, subject to great fluctuations; 2)

[1] Are Plants of Sea Beaches and Dunes true Halophytes? Bot. Gaz. xxxvii (1904), p. 424.

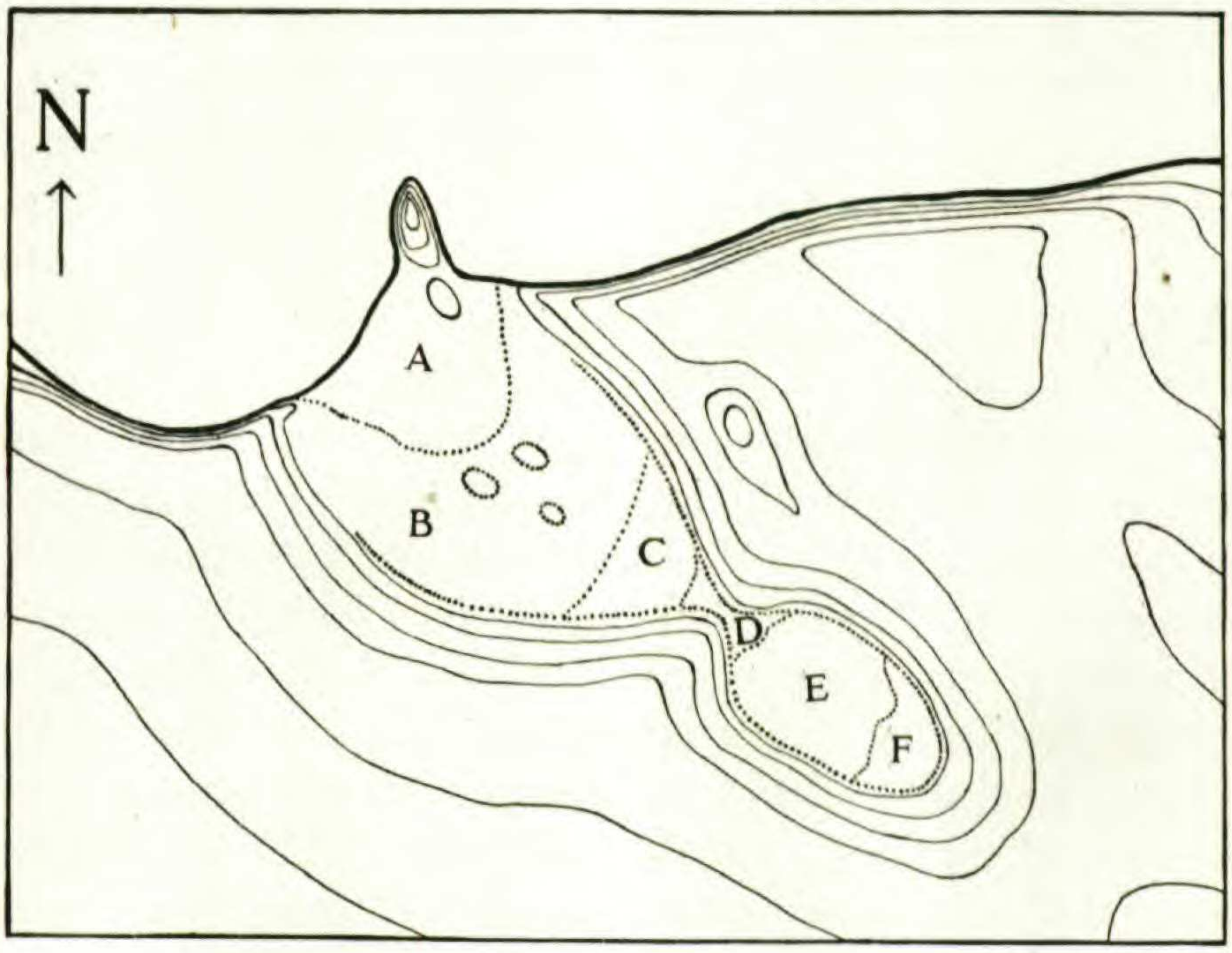
[2] Relation of Soil and Vegetation on Sandy Sea Shores. Bot. Gaz. xlvii (1909), p. 85.

that the plants of sea beaches are not generally halophytes, in the same sense that the plants of inland saline situations are, but are for the most part merely such plants of normally non-saline habitats as are able to withstand a high salt concentration without injury. These conclusions, considered in conjunction with the fact that a large proportion of the species of the beach and transition zone floras, although not necessarily always found within the limits of tide water, are, nevertheless, seldom found more than a few miles from the ocean, suggest that we may have to alter somewhat our conception of what constitutes a halophyte. The broad geographic ranges of the plants of these two transition zones (in part the same species as those which occur at the head of tide water in the region of the Bay of Fundy [1]) can not be correlated with their adaptability to growth in highly saline situations. If, however, we consider not absolute salinity but the ratio of saline constituents in the soil water, irrespective of absolute concentration, the possibility of correlating geographic range with physiological requirements becomes much greater. A moment's inspection of an analysis of an average soil water (in which the concentration of mineral salts is very slight), will show how comparatively small an admixture of sea water would suffice to bring the ratio of elements into approximate agreement with sea water. Further addition of sea water would increase absolute salinity, but would change ratios very slightly. May it not be a useful working hypothesis that sea water, in whatever dilution, is physiologically normal with regard to the plants of salt marshes and sea beaches, and that their usual local distribution is due altogether to the operation of factors other than chemical? The writer hopes to carry out some experimental work along the line of this suggestion. The constitution of soil water is influenced many miles inland by salt spray from the ocean. "The normal chlorine, or maximum proportion of chlorine (present as common salt or sodium chloride) which may exist in an uncontaminated water, usually varies inversely as the distance from the sea, the range for Massachusetts being from 2.42 parts per 100,000 at Provincetown. . . .to 0.06 parts in Berkshire County. The normal chlorine not only depends upon proximity to the coast, but it is highest on the salient and most exposed parts of the coast, where the surf breaks heavily and the salt spray is wafted inland most freely." [2]

[1] Ganong. The Vegetation of the Bay of Fundy Salt and Dyked Marshes; an Ecological Study. Bot. Gaz. xxxvi (1903), pp. 161, 280, 349, and 429.

[2] W. O. Crosby. U. S. Geol. Surv. Water Supply and Irrigation paper No. 114 (1905) p. 73.

The non-halophilous vegetation of the fresh part of the bog may be somewhat arbitrarily divided into two zones at the point where *Chamaecyparis* drops out of the flora. The zonation here appears to be due to the increasing quantity of salt in the bog water as high tide level is approached. The flora of the landward zone is essentially of the same composition as in those Chamaecyparis bogs of the region which are not open to the direct influence of the sea. Since certain of its species are more sensitive to the action of salt than others, they drop out of the flora at varying distances seaward. That portion of the fresh part of the bog between the Chamaecyparis zone and the transition zone is composed of certain relicts from the flora of the Chamaecyparis bog, together with invaders from other fresh water habitats.



The sketch map shows the six zones, designated, in order from the sea landward, A, B, C, D, E, and F. Plants which belong properly to none of these zones occur in standing water of the marginal fosse,— a well marked topographical feature in the fresh part of the bog, which is by no means obliterated in the upper part of the salt marsh.

In the following lists it has been convenient to group the plants of some of the zones according to manner of growth, as, for example, those of zone F into trees, shrubs, herbs and mosses. Where this has been done, the species of each group are arranged as nearly as possible in the order of their abundance and the groups are separated by lines.

A. Spartina glabra var. pilosa Merr.
Limonium carolinianum (Walt.) Britton.
Spergularia canadensis (Pers.) Don.
Salicornia mucronata Bigel.
Salicornia europaea L.
Salicornia ambigua Michx.

At the edge of the marsh where the waves have thrown up a little gravel occur also:

Spartina patens (Ait.) Muhl.
Distichlis spicata (L.) Greene.

B. Spartina patens (Ait.) Muhl.
Distichlis spicata (L.) Greene.
Juncus Gerardi Lois.
Limonium carolinianum (Walt.) Britton.
Triglochin maritima L.
Gerardia maritima Raf.

Low muddy spots within this zone, from which tide water drains more slowly than from the *Spartina patens* turf, contain part or all of the following flora. They should perhaps be associated with zone A.

Limonium carolinianum (Walt.) Britton.
Triglochin maritima L.
Plantago decipiens Barneoud.
Spergularia canadensis (Pers.) Don.
Gerardia maritima Raf.
Spartina glabra var. pilosa Merr.
Distichlis spicata (L.) Greene.
Scirpus campestris var. paludosus (A. Nels.) Fernald.

At the landward edges of this zone, the water becomes much less salt. Here the *Spartina patens* and *Juncus Gerardi* grow much taller, and are associated with *Agrostis alba* var. *maritima* (Lam.) G. F. W. Mey.

C Scirpus americanus Pers.
Triglochin maritima L.
Spartina patens (Ait.) Muhl.
Pluchea camphorata (L.) DC.
Ptilimnium capillaceum (Michx.) Raf.
Galium Claytoni Michx.

Cyperus Nuttallii Eddy.
Hypericum virginicum L.

Whitened wrack, left by the winter storms, is covered with *Atriplex patula* var. *hastata* (L.) Gray. In unusually wet places, and near the marginal ditch, occur the following species:

Eleocharis palustris (L.) R. & S.
Agrostis alba var. maritima (Lam.) G. F. W. Mey.
Cyperus Nuttallii Eddy.
Pluchea camphorata (L.) DC.
Juncus pelocarpus Mey.
Juncus acuminatus Michx.

Two mosses which grow in the landward part of this zone, but are really characteristic of the next zone, are:

Sphagnum (near Sphagnum dasyphyllum Warnst.).
Amblystegium riparium (L.) Br. & Sch.

D. Spartina Michauxiana Hitchc.
Scirpus americanus Pers.
Cyperus Nuttallii Eddy.
Rhus Toxicodendron L.
Ptilimnium capillaceum (Mx.) Raf.
Agrostis alba var. maritima (Lam.) G. F. W. Mey.
Hypericum virginicum L.
Polygonum hydropiperoides Michx.
Aspidium Thelypteris (L.) Sw.
Decodon verticillatus (L.) Ell.
Vaccinium macrocarpon Ait.
Polygala cruciata L.
Juncus canadensis J. Gay.
Pluchea camphorata (L.) DC.
Apios tuberosa Moench.

Sphagnum (near Sph. dasyphyllum Warnst.).
Amblystegium riparium (L.) Br. & Sch.
Sphagnum (near Sph. obesum (Wils.) Warnst.).

Along this zone, the marginal ditch contains:

Typha latifolia L.
Agrostis alba var. maritima G. F. W. Mey.
Eleocharis palustris (L.) R. & S.

E. Clethra alnifolia L.
Myrica carolinensis Mill.
Rhus Toxicodendron L.
Vaccinium macrocarpon Ait.
Gaylussacia baccata (Wang.) K. Koch.
Gaylussacia frondosa (L.) T. & G.
Ribes oxyacanthoides L.
Pyrus arbutifolia var. atropurpurea (Britton) Rob.

Osmunda cinnamomea L.
Aspidium Thelypteris (L.) Sw.
Rhynchospora alba (L.) Vahl.
Eriophorum virginicum L.
Drosera rotundifolia L.
Lysimachia terrestis (L.) B. S. P.
Epilobium palustre L.

Sphagnum imbricatum var. cristatum f. fuscescens Warnst.
Sphagnum acutifolium var. rubrum Brid.
Sphagnum amblyphyllum var. parvifolium f. tenue sf. capitatum Grav.
Cladonia rangiferina (L.) Web.
Cladonia alpestris (L.) Rabenh.

Along this zone the marginal ditch contains:
Sphagnum cymbifolium var. virescens Warnst.
Typha latifolia L.
Glyceria canadensis (Michx.) Trin.
Decodon verticillatus (L.) Ell.

F. Chamaecyparis thyoides (L.) B. S. P.
Acer rubrum L.
Betula alba var. cordifolia (Regel) Fernald.
Salix rostrata Richards.

Clethra alnifolia L.
Myrica carolinensis Mill.
Rhus Vernix L.
Hamamelis virginiana L.
Rhododendron viscosum (L.) Torr.
Ilex verticillata (L.) Gray.

Ilex laevigata (Pursh) Gray.
Ilex glabra (L.) Gray.
Pyrus arbutifolia var. atropurpurea (Britton) Rob.
Vaccinium corymbosum L.
Viburnum cassinoides L.
Rhus Toxicodendron L.
Kalmia angustifolia L.
Lyonia ligustrina (L.) DC.

Osmunda cinnamomea L.
Aspidium Thelypteris (L.) Sw.

Sphagnum medium var. purpurascens Warnst.
Sphagnum flavicomans (Card.) Warnst.
Sphagnum imbricatum var. cristatum f. fuscescens Warnst.

In the marginal fosse at the head of the bog grow:

Sphagnum imbricatum var. affine (R. & C.) Warnst.
Sphagnum pulchricomum v. pulcherrimum f. sphaerocephalum Warnst.
Onoclea sensibilis L.

The chief interest of the foregoing lists will lie in the fact that the chlorine content of the bog water was determined at the boundaries of the zones, and at the point of each zone where its characteristic flora was best developed. The few such data which have been published regarding littoral floras refer, for the most part, not to marshes or bogs but to the strand, where the conditions of plant growth are very different. The amount of sea water which would have to be mixed with pure water in order to bring the chlorine content of any given sample up to the value found by analysis was calculated on the basis of a chlorine content of 1.82% for sea water. The samples were collected along the longitudinal axis of the bog, from holes made by pushing a post into the peat to the desired depth. After the water in the holes had attained its level and had settled somewhat, a sample was taken from each with a pipette. Chlorine was determined by titration with tenth normal silver nitrate, using potassium chromate as an indicator. An obscure end point of the reaction due to the coffee color of the water was avoided by greatly diluting each sample and by making titrations by artificial light. It was not even necessary to filter the samples. In the following table of results, an asterisk indicates that a zone is more or less regularly inundated by sea water at high tide. Appropriate values for sea water are not filled in, however, because the fresh water table underlies the whole marsh, and would, in fact, coincide with its surface if it were not for downward displacement by sea water left on the marsh after high tide. Even at the line of stumps along the water's edge, peat from below low tide level is appreciably less salty to the taste than that from higher up. It may be that the salt concentration in the water from which deep rooting species draw their supply is much less than in sea water.

	Cl. concentration			% sea water			ΔOsmotic pressure in mm.		
Zone	Sea-ward limit	Center	Inland limit	Sea-ward limit	Center	Inland limit	Sea-ward limit	Center	Inland limit
A	*	*	*	*	*	*	*	*	*
B	*	*	$\frac{n}{16}$	*	*	11.2	*	*	2110
C	$\frac{n}{16}$	$\frac{n}{363}$	$\frac{n}{375}$	11.2	0.51	0.48	2110	102	95
D	$\frac{n}{375}$	$\frac{n}{217}$	$\frac{n}{158}$	0.48	0.82	1.12	95	180	220
E	$\frac{n}{158}$	$\frac{n}{214}$	$\frac{n}{217}$	1.12	0.84	0.82	220	180	180
F	$\frac{n}{217}$	$\frac{n}{1000}$	$\frac{n}{1700}$	0.82	0.18	0.11	180	35	21

In explanation of this table little need be said. The first three columns give the amount of chlorine found on titration, the second three columns the corresponding admixture with sea water, assuming the normal chlorine of the ground water to be negligible, and the last three columns give the approximate increase in osmotic pressure which would correspond to such admixture. Perhaps the most remarkable fact shown is that in the transition zone, D, the salinity is less than in the next zone landward. Of course this would not be true all the year round. That such a condition may sometimes obtain is due to the fact that zone D marks the line of intersection of the fresh water table and the marsh surface. Along this line there is constant upward seepage of fresh water, which washes away salt spray which is blown upon the surface. In zone E, on the other hand, the water table is below the surface and all salt spray sinks in, to be removed only by downward displacement. There is furthermore constant evaporation of capillary water from the surface in zone E, which results in an accumulation of salts at the surface, during dry weather. It is obvious that from zone D landward the osmotic pressures are too slight to influence the distribution of the flora.

The evidence afforded by the Quamquisset bog in regard to coastal subsidence remains to be considered. A line of soundings along the longitudinal axis of the bog disclosed a brown Sphagnum peat containing so many stumps and prostrate logs of *Chamaecyparis* that it was only with difficulty that a spot could be found where the sampling apparatus[1] could be pushed down to the sandy bottom without encountering wood. At the narrowest part of the bog, the center of zone D, and from here all the way to the water's edge, where the stumps shown in Plate 82[2] have been exposed by erosion, there are large stumps and logs within a foot of the surface. In this part of the bog the soundings showed depths from eight to fourteen feet, but in most of the holes the peat sampler encountered not the bottom, but wood. A bottom of moderately fine sand, like that found in the upper part of the bog, was reached by a fourteen foot sounding made at the extreme seaward edge of the marsh, at a point outside the escarpment, where the surface is about two feet below extreme high tide level. This proves that there has been no undercutting of the peat by wave action. By wading into the water a short distance, at low tide, the peat bottom was found to be soft and yielding beneath the layer of gravel and boulders which the waves have thrown upon it. From zone D landward to the living Chamaecyparis trees the soundings varied from 7.5 to over 15 feet. Two or three feet of this depth is above high tide level. In this part of the bog, also, difficulty was found in reaching bottom on account of wood, which in several cases was encountered at a depth of 15 feet.

If we accept as the greatest depth of the bog the fourteen feet found at the very edge of the beach, and add to that depth two feet as the maximum height of the tide above the surface at the point where the sounding was made, we get sixteen feet as the depth to which peat extends below high tide level. It has already been pointed out that in Chamaecyparis bogs where the peat contains wood from bottom to top, the water table originally coincided with the floor of the depression. When peat commenced to form in the Quamquisset bog, the floor of the depression must have been at least at high tide level, i. e., sixteen feet higher than at present. We must admit, therefore, a subsidence

[1] The peat sampler used was that devised by Davis, described in Report Mich. Geol. Surv. for 1906, p. 317

[2] This photograph is reproduced through the kindness of Mr. A. H. Moore, who made a special trip to Woods Hole in order to take it.

of at least sixteen feet, (probably more), since the first peat was laid down. Only two other suppositions could possibly be made: 1) that the *Chamaecyparis* grew in sixteen feet of water (!), or 2) that the water table sloped *away* from high tide level and was sixteen feet below it at a distance surely less than half a mile from the sea. The latter proposition is almost as absurd as the former, since in the loose drift deposits of the Cape Cod district the water table reaches the surface at approximately high tide level, and its gradient is always toward the sea.

In Shaw's paper (l. c.) bog "x" is described as a Chamaecyparis forest on a floating mat, covering a pond, the center of which is still open water. That this is not correct has already been pointed out. The condition of this bog is not that of youth, but of old age. On account of the fact that it is not far above sea level, the surface of the water table, approaching sea level as a limiting state, has remained almost stationary, while the land has subsided. The growth of peat has not kept pace with the (relative) rise of the water, and the result is that the bog is being drowned. The pond at the center is increasing in diameter and water stands two or three feet deep among the trees during much of the year. This bog is as truly a record of the subsidence of the region as the Quamquisset bog.

From a study of the Quamquisset bog a very rough idea can be gained of the rate at which subsidence has taken place. If we accept Shaler's estimate of a tenth of an inch a year as the rate of peat deposition (under varying conditions it may be much more or much less than this), a period of approximately 2300 years would have been required for the growth of sixteen feet of peat below high tide level (zones A–D) and three feet above high tide level (zones D–F). If we assume that during this time the subsidence has been the logical minimum, sixteen feet (i. e., that the bottom of the bog when peat began to form was at high tide level,— an improbable supposition) we obtain as the rate of subsidence eight and a half inches per century. This estimate accords with that reached by Prof. C. A. Davis, who has made investigations at other points on the New England Coast. A brief statement of his views in regard to the botanical and geological history of the New England salt-marshes has already appeared,[1] but a more complete account may be expected in an early number of Rhodora.

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[1] Bull. U. S. Geol. Surv. 376 (1909) pp. 19–20.